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Citation for published version:

Atlar, M, Aktas, B, Sampson, R, Seo, KC, Viola, IM, Fitzsimmons, P & Fetherstonhaug, C 2013, 'A multi-purpose marine science and technology research vessel for full-scale observations and measurements', Paper presented at 3rd International Conference on Advanced Model Measurement Technologies for the Marine Industry , Gdansk, Poland, 17/09/13 - 18/09/13.

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Early version, also known as pre-print

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A MULTI-PURPOSE MARINE SCIENCE & TECHNOLOGY RESEARCH VESSEL FOR FULL-SCALE OBSERVATIONS AND MEASUREMENTS

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In order to support the marine research, teaching and consultancy activities in the North East region of England, Newcastle University recently replaced their aged, slow-speed mono-hull research vessel with a modern and relatively high-speed catamaran, "The Princess Royal". The hullform of the new research vessel was designed by the School of Marine Science and Technology staff and students. This was based on the catamaran application of the displacement type Deep-V hull forms with a novel anti-slamming bulbous bow and tunnel stern. The vessel was built in aluminium alloy and by a local North East yard.

The Princess Royal lends itself to be used as a multi-purpose science and technology platform with a flexible speed range for a wide variety of full-scale marine measurements and observations. Her main duties include conventional trawling, sampling, dredging, marine wild life observation, wind farm/renewable device support, performance monitoring, coating/fouling inspection, cavitation and noise research. She is equipped with a moon pool facility for the deployment of remotely operated vehicles and which is complemented by a wide range of hydraulic cranes and by an hydrographic winch. The starboard propeller shaft is fitted with a load cell to measure thrust, torque and shaft bending moment. A motion sensor combined with vertical wave radar, EM speed log, propeller observation windows, borescope apertures, hydrophone facilities and wide array of marine science equipment further complements the equipment on board.

This paper reviews the mission profile and various up to date technical details of the Princess Royal. The current capabilities of the vessel through recent research, teaching, engagement and industrial consultancy activities are highlighted since her entry into the service by October 2011.

1. Introduction

The School of Marine Science & Technology (MAST) of Newcastle University (UNEW) was formed a decade ago by the amalgamation of two over hundred year old departments: the Department of Marine Technology (DMT) and the Department of Marine Science and Coastal Management (DMSCM). The newly formed school aims to meet the challenges of the 21st century research and education as well as other needs of the Marine Society in the North East of England. Traditionally DMSCM always had research vessels since its foundation in the late 19th century to support its activities, including the last research vessel (RV), the RV "Bernicia". She was built in 1973 as rather slow speed mono-hull vessel with a

max eight knots speed hence getting too old and not able to meet the modern demands of the new school (MAST) especially for the demands of the marine technology group.

Driven by the above fact the expertise and experience within the new school has enabled the new research vessel “*The Princess Royal*” (Figure 1) to be conceived, designed and developed in-house with support from the close network of Marine Alumni and friends of Newcastle University in the marine industry towards the end of 2011. The key issue in the mission specification was the multi-purpose and flexible role of the RV enabling it to meet the marine science and technology needs as well as any commercial requirements. For example, the vessel was to be able to provide a respectable bollard pull for bottom trawling activities and to keep station at a required position as well as to achieve a top speed of 20 knots in calm weather for special missions, and 15 knots service speed up to sea state code SS4 with acceptable motion levels. More specifically it was expected that the new RV would be a modern state-of-the-art platform to be operated by MAST and used in both the marine science and technology fields for teaching and research as well as chartering for consultancy. As a result, a wide range of oceanographic deck equipment and features were specified including the deployment of remotely operated vehicles (ROV) through its moon pool, utilisation of modular laboratories, handling of a high-speed rigid inflatable boats (RIB) and the introduction of an observation tower for sea mammals, birds, *etc*, all of which required a large useable deck area of stable catamaran with relatively high-speed.

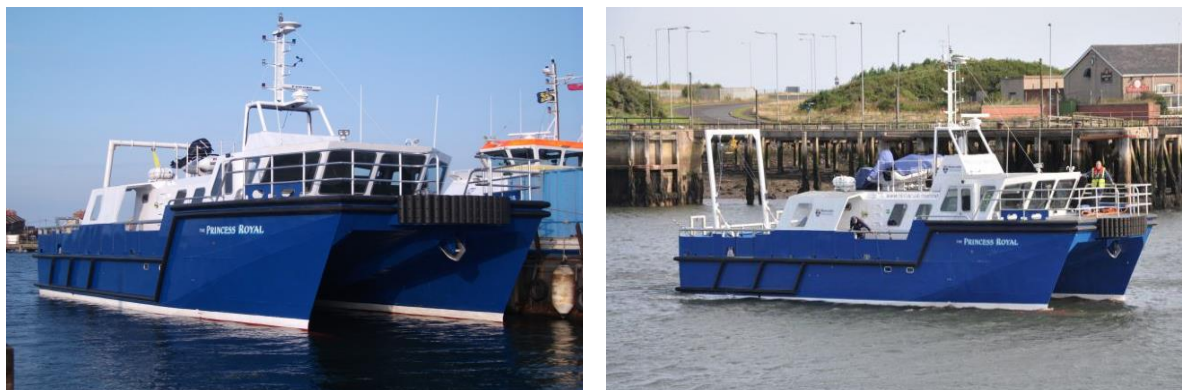


Fig. 1 – Views of Newcastle University’s new research vessel, “The Princess Royal”

High-speed craft are typically limited in their load carrying capacity and suffer from performance degradation related to speed and ride quality in rough seas. This is particularly true for planing and semi-planing craft. If a commercial fast craft is to be competitive it should benefit from a superior seakeeping performance and the efficient load carrying capability of displacement type hull forms as opposed to the inferior planing hull or other complex hull form concepts. Although there are many types of fast craft using mono-hull forms, multi-hulls, catamarans in particular, exhibit a much greater potential for fast ship applications due to their slender hulls, despite their inherently poor seakeeping performance leading to a reduced speed disadvantage in waves.

Improvement of seakeeping behaviour of fast catamarans is a real challenge to naval architects and this challenge has been tackled at Newcastle University by introducing the application of the displacement type Deep-V hullforms in catamarans. This was because the superior seakeeping performance of the displacement type Deep-V hullforms has been well recognized in conventional mono-hull vessels and there are numerous naval and commercial applications of this hull-form concept already in existence. However there was no focused research to look into marrying the superior seakeeping and load carrying capability of the displacement type Deep-V hullforms to the superior speed capability of catamarans. This was until the subject research was initiated by Atlar [1] in mid-90s and supervised to numerous undergraduate and postgraduate projects which eventually resulted in the application of the world's first systematic Deep-V catamaran series [2,7], named UNEW-DVC hereafter.

The accumulated knowledge in the Newcastle University research activities on Deep-V catamarans recently attracted the commercial interest of the local North East boat builder (Alnmaritec Ltd) to adopt the Deep-V hullform for the development of a small catamaran fleet to be used in River Thames [4, 5]. This was through a competitive tender for the Port of London Authority (PLA) to build a fleet of four Harbor Patrol Launches in 2008. The fleet would be developed specifically to support the 2012 London Olympic activities. The winning Deep-V catamaran concept was further developed to the PLA's requirements by the Newcastle Research team who designed and further optimised the entire hullform and propeller using their own database in combination with advanced numerical and experimental methods. This presented a basis vessel with a 13.5m length, 11t displacement and 21.5 knots max speed. The PLA awarded this contract to the yard with the condition that the first of the fleet ("*Lambeth*") would demonstrate the worthiness of the new concept meeting the PLA's requirements prior to their approval to build the remainder of the fleet. *Lambeth* successfully fulfilled the PLA's expectations in her trials in May 2009 (Figure 2) and the remaining three vessels "*Southwark*", "*Kew*" and "*Barnes*" were completed through 2009-2011.



Fig. 2 – The first application of the Newcastle University's Deep-V catamaran concept- Port of London Authority harbour patrol launch, "Lambeth"

The fleet has been operating successfully without any design flaws and fulfilling their main mission to support the 2012 London Olympics as confirmed in various user testimonies. They also played a very significant security and patrol task during the Queen's Diamond Jubilee Pageant. Alnmaritec Ltd further exploited this basic Deep-V catamaran concept by building

the survey vessel “*Thames Guardian*” with a slightly larger size (14.5m and 14t displacement) and higher speed (25 knots) for Briggs Marine & Environmental Services. They used the same hull form for very different mission involving research and survey for the UK Environment Agency. This vessel was launched in 2011 and has been operating successfully since completion.

The most recent application of the Deep-V catamaran concept, with more innovative bow and after body features, was the design and construction of “*The Princess Royal*” [4, 5]. In addition to the requirements for large deck area, seakeeping and speed capability the new RV was expected to have good shallow water operation ability and drying out (beaching) capability on sands in a similar manner to the way in which the local Northumberland fishing boat “*cobble*” often does (Figure 3). Partly because of beaching and partly because of the evolved nature of their designs, these authentic boats have a distinctive droop bow and tunnel stern features, the latter to accommodate and protect their propellers. It is ironic that the proposed Deep-V hullform concept for the new RV had these features in an innovative way by adopting “anti-slamming bulbous bow” to further improve the efficiency of her hullform, arguably adapting the hullform of the cobbles for the current mission profile of *The Princess Royal*.



Fig. 3 – Views of authentic Northumberland fishing boat “Cobble” with her characteristic droop bow and tunnel stern features

The Princess Royal was constructed by Alnmaritec Ltd and named by HRH Princess Anne prior to entering into service in October 2012. She is currently the latest and largest application of the Newcastle University’s Deep-V concept with a length of 18.9m length overall and a lightship displacement of 36 t. The market value of the Princess Royal is £1.25M. Since entering into service the impact of the research vessel on research and teaching in Newcastle University has been remarkable. This is allied with ever increasing consultancy activities and growing reputation in the North East. The vessel has been operating successfully without any design flaw, as have the other five Deep-V catamaran applications of the Newcastle University’s UNEW-DVC concept.

The remainder of this paper includes: a mission profile and certificate review of the Princess Royal in Section 2; a review of the technical specifications in Section 3; some key operational experiences are given in Section 4; and a portfolio of activities in her utilisation

are presented in Section 5 since her entry into service. The paper concludes with general conclusions on the design and utilisation of the vessel based on the experiences so far.

2. Mission profile, certificate & management

Within the framework of a multi-purpose and flexible RV requirements, the mission profile of The Princess Royal includes the following main duties to meet the current marine science and technology demands of Newcastle University and the North East region of England:

- Conventional surface, mid-water and bottom trawling
- Use of static fishing gear
- Water and plankton sampling up to 200 m
- Bottom dredging; sea floor coring and rock dredging
- Soft sediment sampling and sea floor photography
- Marine wild life observation
- Platform for wide variety of marine science & technology research programmes
- Wind farm and wet renewable support
- Performance monitoring and antifouling investigation
- Cavitation, vibration and noise investigation
- Bio-fuel investigation
- Undergraduate & postgraduate teaching programmes
- Charter for government and commercial organisations
- Full scale experimentation
- Vocational training
- University – industry collaboration

In fulfilling the above mission profile, The Princess Royal has been certified by the Authority of the Maritime & Coastguard Agency (MCA) of the UK Department for Transport under the Code of Practice for the Safety of Small Workboats & Pilot Boats. She has MCA Category 2 certificate implying that the permitted area of her operation is 60 miles from a safe haven while she is not permitted to operate at sea continuously more than 24 hours. The maximum passenger number to be carried is 16 including the crew and her unique registration number is S11WB0181059. Call sign of the vessel is 2EYM2; MMSI no: 235089188 and her port of registry is Blyth, UK.

Her current crew includes a well-experienced skipper and a deck hand who is also qualified to steer the vessel. The vessel has technical support from the technical personnel of MAST whenever is needed as well as an academic person to oversee her activities.

3. Technical specifications

3.1 Main particulars and hydrodynamic design review

The specification on the preliminary dimensions of the vessel was due to a combination of needs driven by her mission profile, berthing restrictions and economical considerations. These main dimensions were applied to a catamaran with Deep-V hull lines because of the background reviewed in the Introduction (Section 1) of this paper. By taking 19m L_{OA} as the limit for the new vessel and bearing in mind the other limitations in terms of the maximum beam, water and air draught, preliminary weight and power estimations were conducted for four different candidate hullforms in a parametric study described in [4]

Having determined the preliminary dimensions and basic hull lines, the next step was to optimise the hull lines within a reasonable envelope of the preliminary dimensions. In this task the main focus was to improve the calm water performance of the hullform as well as the performance in waves. In this respect, it is known that the anti-slamming bow form of the hull would improve the slamming characteristics of the UNEW-DVC series as pioneered by Serter in mono-hulls [10, 11]. However, it was decided to combine the anti-slamming bow with an optimised bulb form to further improve the resistance and vertical motion characteristics. Optimisation of the after body part of any vessel is not an easy task due to complex viscous flow activity interacting with the vessel's propulsor which operates in the wake of this flow. The after body of the proposed true Deep-V hull had to be prammed by a gentle cut-up angle of 14° to accommodate the propellers and stern gear to prevent their extension below the keel line. Furthermore it was decided to introduce a shallow tunnel (or propeller pocket) to enable the fitting of a relatively large diameter propeller with reduced tip losses and reduced shaft inclination. Such a shallow tunnel would also help to smooth the sharp wake peak at the bottom of the V shape hull in the propeller plane as well as provide more flexibility for relaxed tip clearances. These unusual bow and stern features in a way are contemporary applications of the Northumberland Cobble features on a catamaran.

The main appendages of the vessel were specified as conventional rudders, shafts, I-brackets and bow thruster openings. In addition, initially the vessel was equipped with a partial central box keel in front of the hull rising at the aft in order to support the hull for beaching and dry docking, as successfully used in the PLA boats. However this latter appendage was converted to a skeg by extending it all the way from the rising point to the rudderstock to provide more protection to the propeller and stern gear from possible grounding and tangling with nets, fishing gears, *etc.* This skeg arrangement was preferred by the skipper with no compromise and hence no specific optimisation process was applied on the appendages apart from designing such an unusual skeg (with a 4.5m length, 0.5m max height and 0.3 m max width) that had to be structurally sound as well as generating minimal drag at high speeds.

The above water hullform was dictated by the maximum air draft that imposed a height limit to the wheel house on the main deck. A reasonable wet deck clearance was allowed to avoid frequent wet deck slamming as no deadrise or jaw was introduced to the wet deck to lessen the impact of such slamming in order to keep the vessel depth and production cost low. She

was given a reasonable bow flare with sufficient length to cover the foremost point of the bulb protrusion. Several different wheel house configurations were considered and the final shape is shown in Figure 4, which also displays the above mentioned fore and aft bodies as well as the appendage details. Table 1 displays the main particulars of the Princess Royal (as built).

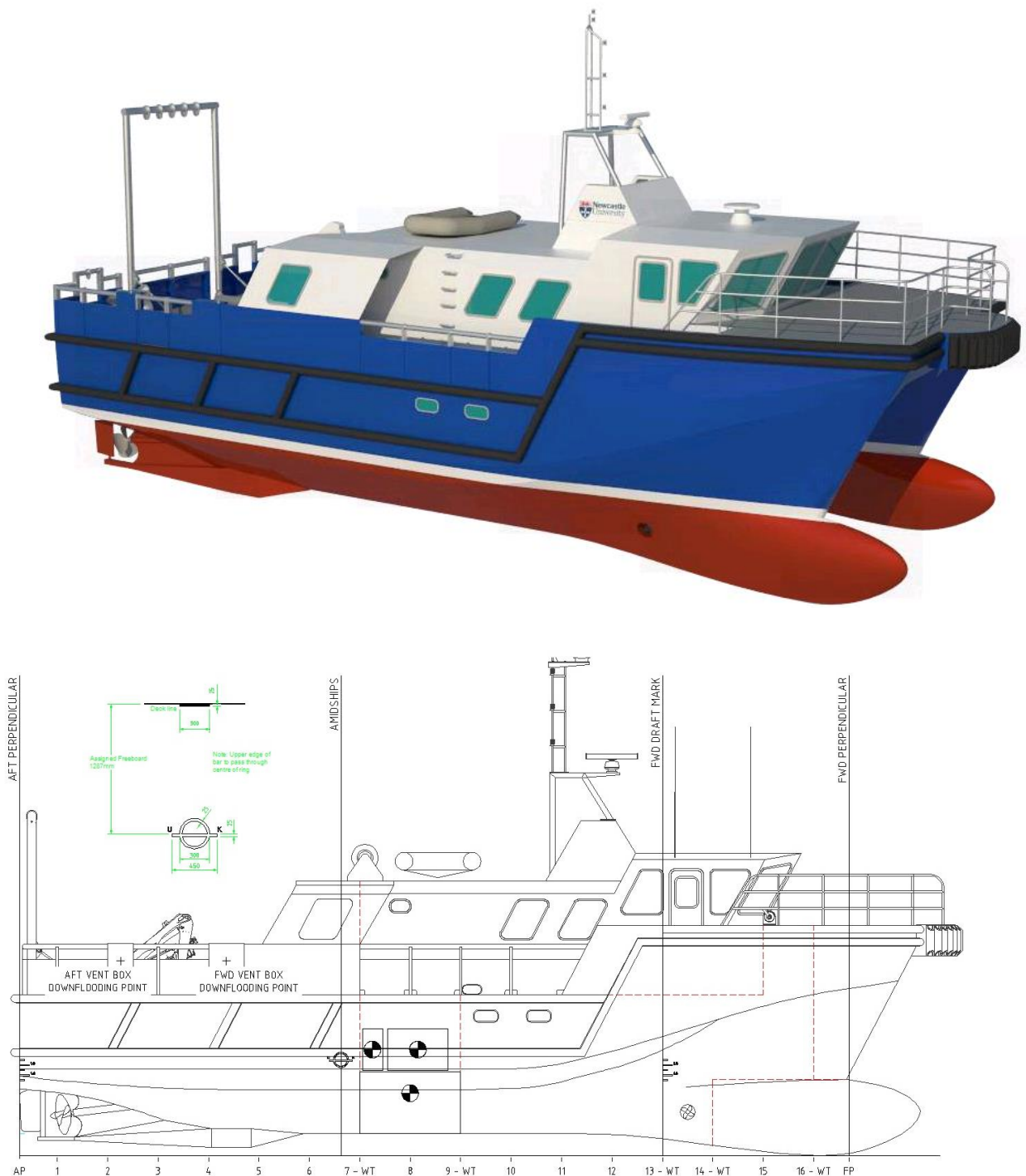


Fig. 4 – An isometric view (above) and profile view (below) of The Princess Royal

Table 1 – Main particulars of The Princess Royal as built

Launching date & place	11 August 2011 & Alnmaritec, Blyth (UK)
Hullform	Displacement type Deep-V catamaran with symmetric demi-hulls
Length overall	18.88 m
Length BP	16.45 m
Breadth Moulded	7.03 m
Breadth Extreme	7.34 m
Depth moulded	3.18 m
Demi-hulls separation (C_L to C_L)	4.9 m
Displacement (Lightship)	36.94 t
Draught (Lightship) (Amid - FP - AP)	1.65 m – 1.6 m – 1.7 m
Deadweight data	7.32 t (Excluding 2 t of deck cargo)

Perhaps the most challenging aspect of the design was the selection of the propulsion system, a choice that was governed by the mission profile of the vessel, efficiency and production cost. The vessel has an unusually wide operating speed range (0-20 knots) with three prominent sub-zones: which are 0-3 knots zone for station keeping and trawling; around 15 knots zone when operating in service; and around 20 knots top speed zone in calm weather for special missions and emergency situations. Because of this operating profile and in spite of her relatively high-speed mission, the water jet option was ruled out due to lower efficiencies at service speed and below, as well as the bollard pull requirements. Although the use of controllable pitch propellers could have been a good choice considering her distinctively wide ranging operational profile, this option was also ruled out since a conventional fixed pitch propeller can be compromised effectively to avoid the lower efficiencies of a CPP due to previously discussed reasons, as well as its complexity and high cost. As a result, a 0.75m diameter conventional fixed pitch propeller was designed for the 15 knots service speed, whilst still ensuring a minimum of 3t bollard pull at the engine's maximum torque, as well as providing a 20 knots top speed. In order to reduce the risk of one blade entering the shallow tunnel whilst another is simultaneously exiting, which could amplify the magnitude of the vertical blade rate forces [6], a 5-bladed propeller was selected, whilst the optimum values of pitch/diameter ratio and blade/area ratio were determined as $P/D = 0.8475$ and $BAR = 1.057$, respectively. These initial particulars were derived from the basic design of the propeller based on the Wageningen B-Series data. Tip clearance was selected to be 15% of the diameter at the top while a 10% clearance above the extension of the skeg plating was allowed. The clearance of the boss centre from the rudderstock was 0.5D

whilst the shaft lines had a 7° static inclination dictated by the engine location in the hull and the gearbox selection. The selected engines have 2 x 602 brake horsepower with integrated gearboxes at a gear ratio of 1.75:1. Direct drive connection was selected considering its simplicity, weight, cost and reliability. Further optimisation of the propeller was conducted by going through a state-of-the-art wake adaptation and design analysis stages in terms of the efficiency and cavitation performances, respectively, using numerical methods. Table 2 shows the main particulars of the designed propellers as well as the selected engine and gearbox details, which are discussed further in Section 3.3.

As far as the seakeeping performance was concerned, it is inherent with the Deep-V forms that the seakeeping behaviour is expected to be superior, at least when compared with other counterpart conventional catamarans [3], while catamarans are inherently better in manoeuvring compared to mono-hulls due to their twin hull configuration. In addition, The Princess Royal was fitted with two bow thrusters to improve the manoeuvring performance further. The results of a strip theory based seakeeping analyses indicated that the vessel would be operable up to state sea code SS4 maintaining her service speed of 15 knots at acceptable level of motions and accelerations in the North Sea environment combined with the wave spectrum prescribed by the International Towing Tank. Although the application of the International Maritime Organisation manoeuvring criteria to a catamaran of this size does not have any legal implication, these criteria were applied for turning and zig-zag (yaw checking) manoeuvres and it was noticed that the critical parameters of these manoeuvres comfortably comply with the criteria since catamarans are inherently turning unstable and directionally stable.

In order to support the design activities, two sets of separate but complementary model tests were conducted into two different towing tanks with different sizes of model, as shown in Figure 5. A 3.5m larger model (with a scale ratio $\lambda = 5$), which formed basis for the main design activities, was tested in the 160m long Ata Nutku Towing Tank of the Istanbul Technical University (ITU), while a 1.5-m smaller model ($\lambda = 12$) was tested in the 40 m long Newcastle University (UNEW) towing tank in order to complement the larger model tests. The model experiments in the ITU tank included calm water resistance tests, soft paint tests for the bare hull and appended hull in the fully loaded and ballast conditions, and also a wake survey and self-propulsion tests with a five bladed stock propellers. These experiments were supported with further flow observations around the bow and after body of the vessel using tufts in the ITU Circulation Channel facility.

Table 2 – Propeller, engine and gearbox particulars of The Princess Royal

Propeller particulars	
Number of propellers per shaft (& type)	2 (fixed pitch)
Propeller diameter (D)	0.75 m
Pitch to diameter ratio (P/D) at 70% of the radius	0.8475
Expanded blade area ratio (EAR)	1.057
Number of blades	5
Rake angle	0°
Skew angle (back)	19°
Direction of rotation	Port-left turning / SB-right turning ; outwards
Hub dia. to propeller dia. ratio	0.18
Blade thickness to propeller dia. ratio at 20% of the radius	0.04
Blade loading distribution (radially)	Wake adapted
Blade loading distribution (chordwise)	NACA a=0.8
Thickness distribution	NACA 66 modified
Material	Ni-Al-Br
Engine particulars	
Number of engines (& Type)	2 (QSM11-610 HO Cummins Mercruiser Diesel)
Power rating of each engine	449 kW (602 BHP) @ 2300 rpm
Cylinder-Displacement-Bore-Stroke	6 - 10.8lt – 125mm – 147mm
Fuel system	CELECT
Aspiration	Turbocharged – seawater after cooled
Fuel consumption at rated speed	117 litre/hour
Gearbox particulars	
Number of gearbox (& Type)	2 (QuickShift Twin disc marine transmission – MGX 5114 A intermediate duty)
Reduction ratio	1.75:1
Input speed limits	330 rpm (min) / 3000 rpm (max)

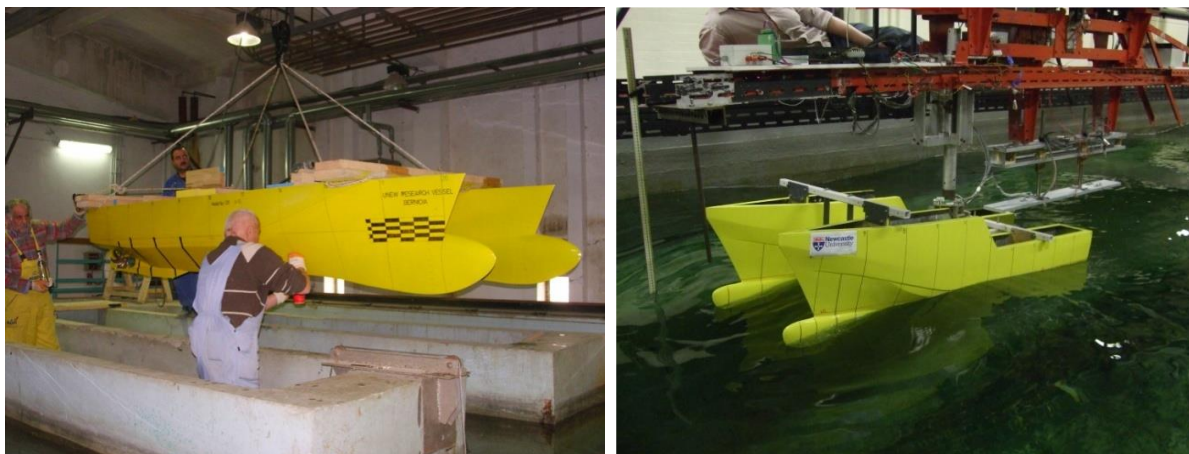


Fig. 5 – Two different size models tested in the ITU tank (3.5 m on the left) and Newcastle University tank (1.5 m on the right)

In fact the tests at ITU included three stages as follows: First stage tests included the initial ballast and full load design conditions with the 1st version of the anti-slamming bulb that displayed some spray at high speeds and hence modified as reported in [12]; Second stage tests comprised the final bulb geometry and the self-propulsion tests conducted with the designed propeller at the same initial design loading conditions as reported in [13]; Third and final stage tests were conducted after she was launched in order to represent the more realistic conditions in terms of her “as built” displacement and trim as reported in [14]. The final tests were conducted because the launched vessel was heavier than her initial design conditions due to a variety of reasons and weight controlling difficulties of the yard as discussed later in Section 4 of the paper.

Limited seakeeping tests were also conducted in regular head sea conditions at the design speed. Similarly, the tests in the UNEW Towing Tank, which also formed basis for the final year projects of a group of undergraduate students, involved bare hull calm water resistance tests and seakeeping tests for a wide range of wave frequencies in head and following seas at zero speed and service speed for the latter. Separate wind tunnel tests were also conducted with a specially made wooden above water model (with a scale ratio $\lambda = 12$), to predict the wind resistance characteristics of the above water hullform with two different wheel house structures in the UNEW Combined Wind, Wave and Current Tank facility. The results of these tests conducted by the Newcastle students were reported in [11].

In complementing the above group of model experiments, further model tests are planned in the UNEW’s Emerson Cavitation Tunnel as part of the on-going EU project (FP7 SONIC) and hence a truncated (dummy) model of the starboard demi-hull has been constructed with $\lambda = 3.5$ to accommodate a 0.214m diameter model propeller. This model will be used to conduct cavitation, hull pressures and underwater-radiated noise tests, which will be correlated with the measurements full-scale trials to be conducted with The Princess Royal.

3.2 General arrangement, deck equipment and construction review

As shown in the General Arrangement plan, Figure 6, the island wheel house is positioned well forward to leave a large aft working deck of approximately 40 m², with an “A” frame and winch plinths and a small foredeck with anchor chain box. The wheel house is fully enclosed and contains a store cupboard, workbenches, student/scientist seating, helm station, galley and separate WC. A settee is fitted around a large table on the port side, providing seating for up to eight people. Below decks, crew overnight accommodation for up to four crew is located in two twin cabins with locker space for personal effects. The forward portion of the wheel house was raised to provide a segregated and spacious helm area with suspension seating for the navigator and two crew. The control console is fitted forward with a chart table on the port side as well as the control and monitoring panels for the propulsion, steering, navigations, communications, alarms and domestic service equipment.

The small foredeck has a centrally positioned electrical winch and chain box. The aft working deck is surrounded by a 1-m high bulwark with suitable openings at the sides and a large gate at the aft. A 3t Hydraulic A-Frame is situated at the aft of the working deck with 3.5 m clearance. A pair of 2t Hydraulic Trawl winches is fitted aft, allowing safe access elsewhere during towing operations. In the centre of the working deck, a 1t auxiliary winch is mounted for use either over the side or with the A-frame. A Hydrographic Slip Ring, winch is also provided for handling cable for scientific equipment, is located at the rear end of the wheel house roof. A 6.5tm Hydraulic Knuckle Boom crane capable of transferring equipment from the quayside to the deck is mounted on a strengthened plinth on the port side. A Moon-Pool (1.6 m x 1.6 m) with a removable cover is situated forward of the capstan plinth so an ROV or transducer or other equipment may be raised and lowered through it. To the starboard side of the working deck is a 0.5t Pot Hauler suitable for deploying equipment over the side is located on the port side of the working deck.

The two main engine hatches and auxiliary machinery space hatches are hinged and flush in the deck and are sized to allow for machinery removal and to provide access for maintenance. Also two additional any time easy access hatches to the engine rooms at the aft are provided with coamings raised above the deck.

The entire vessel was fabricated from aluminium alloy. The main hull is stiffened by a combination framing system comprising of longitudinal angle section stiffeners and deep diaphragm transverse frames and bulkheads.

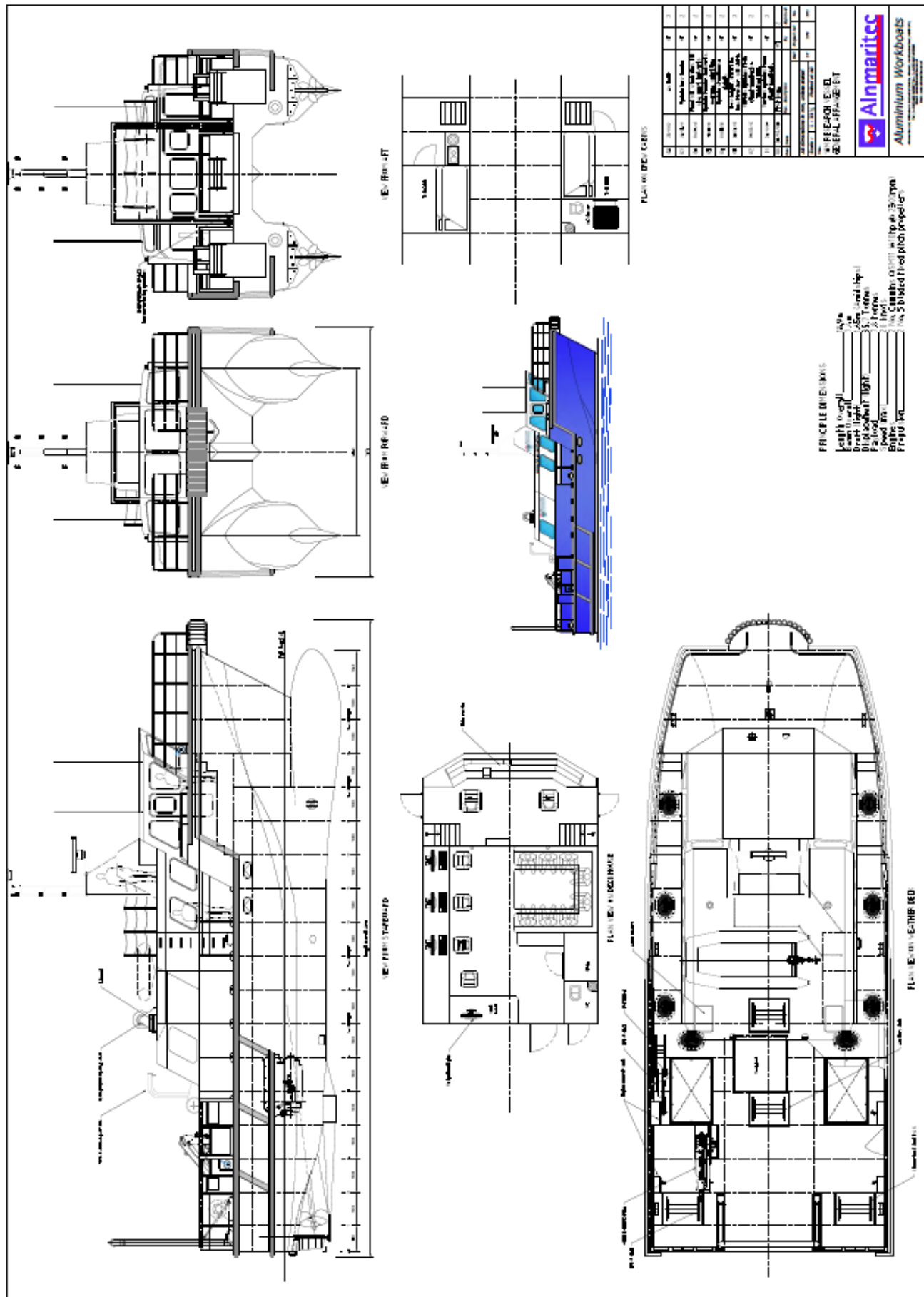


Fig. 6 – General arrangement plan of The Princess Royal

All shell plates, watertight bulkheads and diaphragm type frames (mainly plates) were fabricated from aluminium alloy to BS 5083 (H321) whilst the longitudinal angles, deck beams and deck girders (mainly profiles) were fabricated from BS 6082 T6. Structural design and detailed manufacturing drawings were conducted by the yard sub-contracted to BMT-Nigel Gee.

The building of the vessel was started keel uppermost until the main hull construction was finished and then she was turned over to construct the superstructure and to complete the entire vessel building as shown in Figure 7. The underwater hull was coated by silicon based (Intersleek 900) foul release coating.



Fig. 7 – Various stages of construction of the Princess Royal Hull: Initial stage (left); Turning over (middle) & Final stage (left)

3.3 Main engines, machinery, hydraulics, tanks and electrical system review

The vessel was installed with twin diesel engines each driving through reversing gearboxes to fixed pitch propellers. The main engines are Cummins QSM11-610, 6 cylinders, 4 strokes, 11 litres, direct injected, turbocharged, seawater after-cooled marine diesel engines. The engines can provide 602 BHP (449 kW @ 2300 rpm) each at an Intermittent Rating.

The engines meet EPA Tier 2 IMCO and RCD emissions standards and each is equipped with a fuel pump, heat exchanger, raw water pump, a 24V starter and a 24V alternator. They operate with independent fuel and electrical systems. Fuel oil is stored in two 2700 litres capacity integral fuel tanks fitted within each demi-hull. Such capacity would give the vessel about 400 nautical mile range capability at the design speed of 15 knots based on a typical 98 litre/hour fuel consumption of her engines at 85% maximum continuous rating (MCR). Fuel is delivered to the engines via drawn, stainless steel fuel lines. The engines are resiliently mounted and supporting structure in way of the engine seatings, which are strengthened as appropriate to minimize vibration. Each machinery compartment is provided with a manually activated Stat-X or similar aerosol-generating fire extinguishing system of sufficient capacity to satisfy statutory requirements. Heat detectors are fitted to the machinery compartments giving audible and visual alarms at the control console.

The main engine blocks are fitted with engine mounted freshwater jacket cooling systems with heat exchangers cooled by seawater. The raw water drawn from an intake ball valve from the bottom of the boat and is then taken through a strainer (fitted with an isolating valve) sited in the engine room and circulated through the secondary circuit of the heat exchanger by the engine mounted raw water circulation pump. The raw water is then injected into the exhaust system before discharging at the transom through the exhaust flap. Engine spaces are lined on the deck head and hull sides down to the waterline with mineral wool fireproof insulation panels with an aluminium foil coating. The engines are fitted with reversing marine gearboxes fitted with hydraulically actuated multi-disc clutches rated for light commercial duty with a ratio of 1:175 to suit the propeller demand. The gearboxes are MGX5135 featuring the 'Quickshift' system allowing full control for low speed operations.

As stated earlier the vessel was fitted with twin 750mm diameter five-bladed propellers made from NiAlBr. The propellers are fitted hydraulically to the stainless steel propeller shafts which run through a water-lubricated 'cutlass' bearing in the stern tube through the hull. A water lubricated dripless stern gland is installed on the stern tube. The vessel has two flap rudders, each with 0.31 m² planform area and aspect ratio of 1.2, and they are complete with stainless steel rudderstocks, bearings and seals. Each rudder has a Wills Ridley electro-hydraulic control system, both linked and fitted with a bleed valve for rudder alignment. Reverse control is accomplished by setting the gearbox in the astern position. The vessel is also fitted with an auto-pilot system.

The deck equipment, as described above, is hydraulically operated with controls that are located adjacent to each winch and crane. The auxiliary unit is mounted onto a plinth with locker door to provide an above-deck stowage space. The hydraulics is run from a pair of hydraulic pumps, one fitted to either main engine. Hydraulic oil is stored in two tanks located in the aft of each engine room and two hydraulic pumps are driven from power take-off's on the front of the main engines, each capable of running one of the two main hydraulic systems; one circuit is a low pressure high flow system, which runs the winches, and the other is a high pressure low flow system, which runs the crane and the A-frame.

A matrix 'Hot Pot' type heating system is fitted to provide heating to the wheel house, using waste heat from the main engines. A diesel heating system is also provided for use when the engines are not running. Natural ventilation is provided by mushroom type ventilators fitted to the wheel house roof. Louvered air intake and exhaust vents for the engine rooms are built into the port and starboard bulwarks. The exhaust vents are fitted with electric fans and wired to run with the engines.

There are fresh and black water tanks in the starboard tank space, each with a capacity of 400 litres.

The main electrical system on board The Princess Royal is 24V DC with two wire insulated cable throughout, with all cables, breakers, *etc.* meeting the standards required for marine applications. A 12V system is also provided. Electrical power for engine starting and

domestic use is stored in twin banks of sealed for life DC batteries located securely in custom made battery boxes in the engine rooms. Both battery banks are charged independently via the engine driven alternators and permanently wired cross connections are fitted to allow cross over and paralleling of battery banks. There is a 10 kVA ‘Beta Marine’ generator located in the starboard engine room and remotely controlled from the wheel house with insulated return electrics to power a separate 240 V system. This is supported by 5 kVA (220 V AC, 50 Hz) inverter to provide minimum required electrical power in silent mode. When the vessel is at shore a 240 V, 32 A CE Shore Power Connection is available to supply the same distribution system from the grid. There is also a 240 V battery charger installed for domestic and main engine batteries.

3.4 Special features and equipment review

In order to achieve diverse duties The Princess Royal’s flexible hull form is complemented by her special features and equipment, as well as future upgrading and equipment are planned. Amongst her current features, the foremost part of the main deck was further extended and strengthened to form a special platform to provide the vessel with ability for docking to an offshore wind turbine pile. A comfortable observation tower for wild life (birds, mammals, *etc.*) observations was introduced above the wheelhouse. A shelter area was introduced at the starboard side of the vessel to allow a safe and dry workspace on the main deck for the scientific staff and students in adverse weather conditions. A 3.7-m long high-speed (25 knots) service RIB is provided at the rear part of the wheel house roof that can be deployed by the vessels’ knuckle boom crane. At the aft part of each engine room a pair of circular (D = 150 mm) observation windows were fitted above the propeller as shown in Figure 8.



Fig. 8 – Views of propeller observation window at port side (outside view - left) and starboard side (inside view - right)

Each demi hull was also fitted with two borescoping holes (M20) and four pressure gauge holes (M10) to support the cavitation, vibration and noise research, as shown in Figure 9

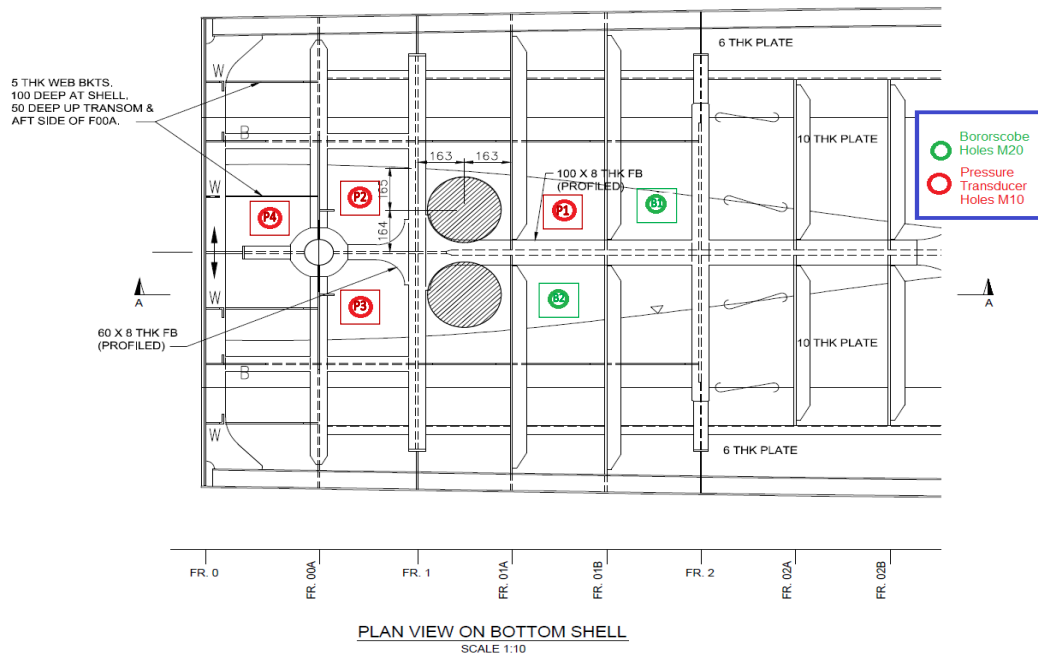


Fig. 9 – Port side propeller observation windows, pressure and borescope holes arrangement

As stated earlier, there are special hatches with coamings from the deck for an easy access to the observation and measurement areas at the aft part of the engine rooms. The starboard shaft is partially modified with a hollow intermediate shaft, which is fitted with a permanent load cell to measure the torque, thrust and shaft bending moment, as well as with a once-per-revolution shaft marker to measure the shaft speed. This system was specially designed and fitted by the Newcastle University's Design Unit. A telemetry system is configured to continuously stream these four channel data and display in graphical as well as in tabulated format by its dedicated software. This is extremely attractive for ship performance investigations when it is combined with fuel consumption monitoring. Currently there is an analogue information for the fuel consumption of each engine provided by the engine manufacturer on the control panel of the wheel house without any dedicated fuel monitoring system with a fuel meter, *etc.* Although the port side shaft can be straingauged anytime for temporary shaft load measurements, the plans are underway to mirror the existing permanent load cell system in the port shaft.

The vessel is equipped with Class A - AIS Transponder (Furuno FA-150) for tracking. Her speed over ground (SOG) is obtained from the Global Positioning System (GPS) system on board. There are three serial ports in the wheel house to receive the entire GPS data in standard NMEA protocol. Her speed through the water (STW) can be obtained from her electromagnetic flush mounted speed sensor (EM200-AGILOG) located at the mid-ship region of the starboard demi-hull. The Princess Royal is also equipped with a combined radar and motion sensor system (RADAC – WaveGuide system) at the bow to measure the vertical motions of the water surface. In addition to her standard anemometer she is fitted with a metrological package (WEATHERPAK Shipboard weather station) including 3-axis

ultrasonic anemometer system with no moving part to measure the horizontal and vertical wind speed and direction. The anti-slamming bulbous bows of the vessel were built in with a provision to accommodate a high frequency hydrophone in each demi-hull. The vessel has a towed sonar system with two high frequency (Magrec HP03) and two medium frequency (Bethis AQ4) hydrophone streamers with 200 m of water-blocked Kevlar braided cable.

In complementing the above specific equipment, miscellaneous marine science related equipment also exist on board. These include, for example, pCO₂ sensor, Phytoflash Fast-Repitition-Rate-Fluorometer, in-line termosalinograph system, CDOM sensor, towed side scan sonar system, CTD block and wire-out meter, marine (MC) balance, day grab, onboard microscopes, various cameras and other observation devices.

4. Operational experiences

The Princess Royal was launched in August 2011. Because of various late changes in her specifications and weight control issues of the yard, she was launched with a 35.7t lightship displacement (as built), while her projected (design) lightship was 30 t. Another word she was built almost 19% heavier than the design lightship condition. Despite this fact she was able to achieve 20.25 knots at 2250 (max) engine rpm with a 37.6t displacement in her maiden trials by the yard and engine manufacturer conducted at SS3 weather in early September 2011.

The current loading conditions of The Princess Royal, as in the Stability booklet, are shown in Table 3. Her full-load condition in the design stage was estimated 36t, which is near to her current lightship condition.

Table 3 – The Princess Royal loading conditions (as in the stability booklet)

Loading conditions	Displacement (T)	Draft (Amid) (m)	Draft (FP) (m)	Draft (AP) (m)
Lightship (Not a sea going con.)	36.9	1.65	1.6	1.7
Light load (Departure)	42.3	1.73	1.76	1.75
Light load (Arrival)	38.2	1.64	1.71	1.68
Full load (Departure)	45.9	1.76	1.86	1.81
Full load (Arrival)	41.8	1.675	1.81	1.74

In order to simulate one of the current loading conditions and to make prediction on her performance, the model tests for the light load departure condition (i.e. 42.3t displacement) were conducted in the ITU Ata Nutku Towing tank. Figure 10 shows the full-scale power predicted based on the self-propulsion tests. According to these predictions, the vessel at this condition would achieve 18.2 knots when the engines are at full-power.

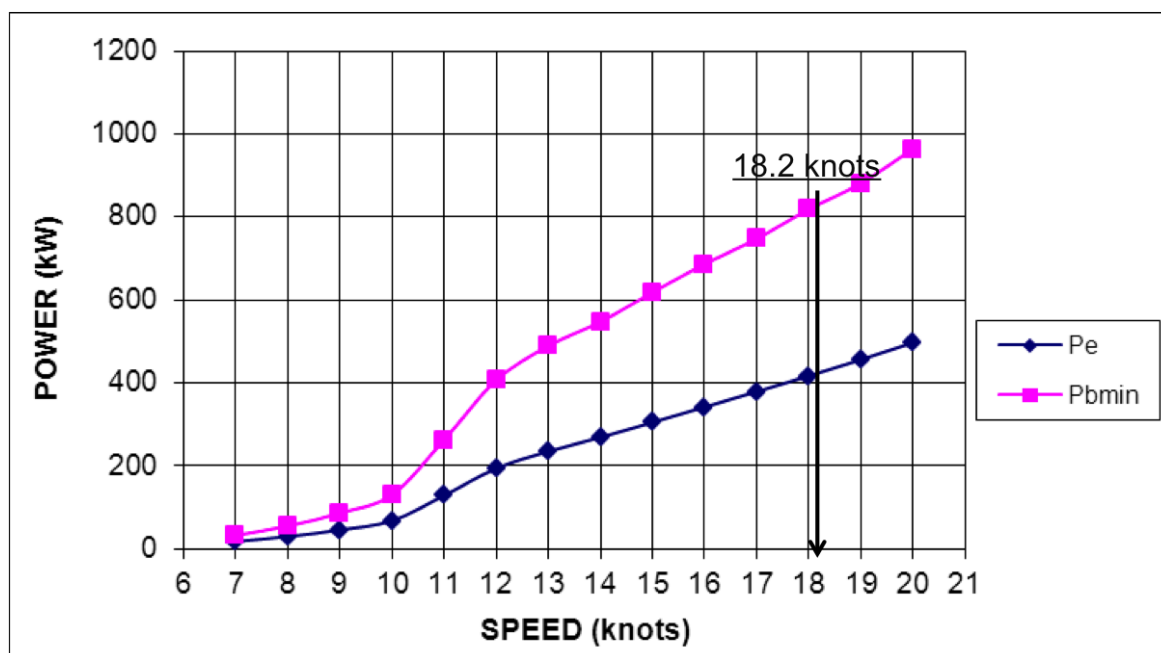


Fig. 10 – Model test based power-speed curve at Light Load (Departure) condition

In order to verify her bollard pull capability, full scale trials were conducted in spring of 2012 after the starboard shaft load cell was installed. For this purpose a dedicated bollard eyebolt was fitted almost in the middle of the aft deck area. These trials indicated 5t bollard pull at 70% MCR as expected. As shown in Fig. 11, there was a reasonable correlation amongst the predicted pull based on the propeller's open water data (indicated as theoretical bollard pull), thrust measurement from the shaft load cell and the pull on the bollard line measured by a portable load cell device.

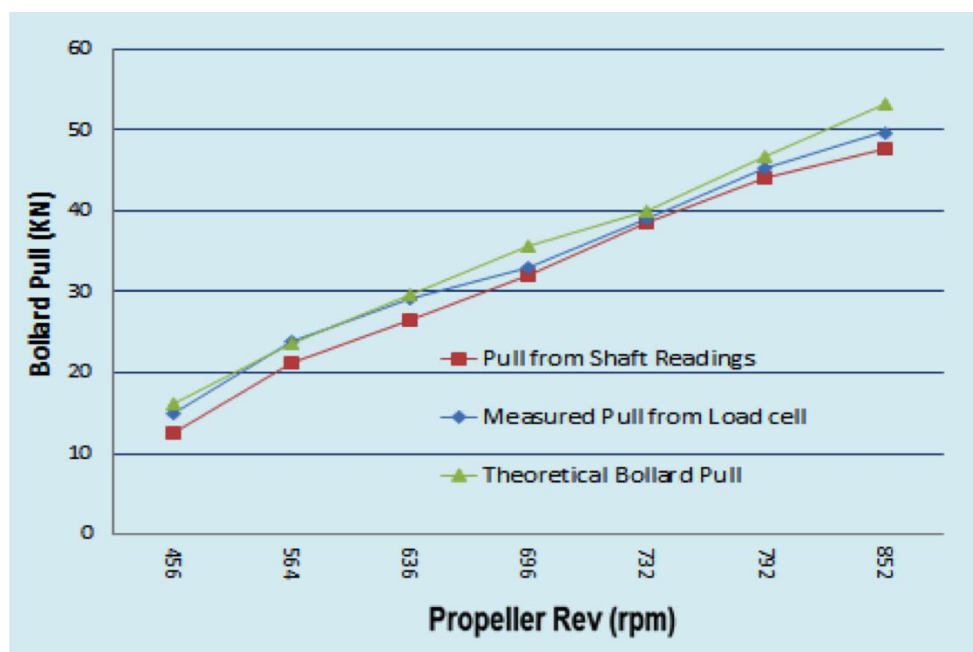


Fig. 11 – Comparative bollard pull data for the Princess Royal

After her final out fit, The Princess Royal had a 0.8° of static trim to aft and this increased underway with increasing speed (e.g. 4.8° at 17 knots) due to her dynamic trim. This was far greater than the dynamic trim measured during the model tests. In order to remedy this situation an MSc study was conducted at the Newcastle University to look at different types of dynamic trim control devices. This study indicated favourable result for an arc shape interceptor design as opposed to a fixed transom wedge, trim tab and integrated transom wedge design with a 1.2° trim reduction, and 5% power saving at 15 knots, as reported in [9]. During her drydocking in summer 2012, these interceptors, which can be controlled manually, were manufactured and fitted to the vessel as shown in Figure 12.



Fig. 12 – Manually controllable interceptor fitted to The princess Royal

In order to investigate the impact of the interceptors on the vessel's performance two sets of power-speed trials were conducted without and with the interceptors in May and July 2013, respectively, both at the near fully-loaded condition. As shown in Figure 13, the positive effect of the interceptors after 14 knots is apparent with almost a 6% power saving at 15 knots.

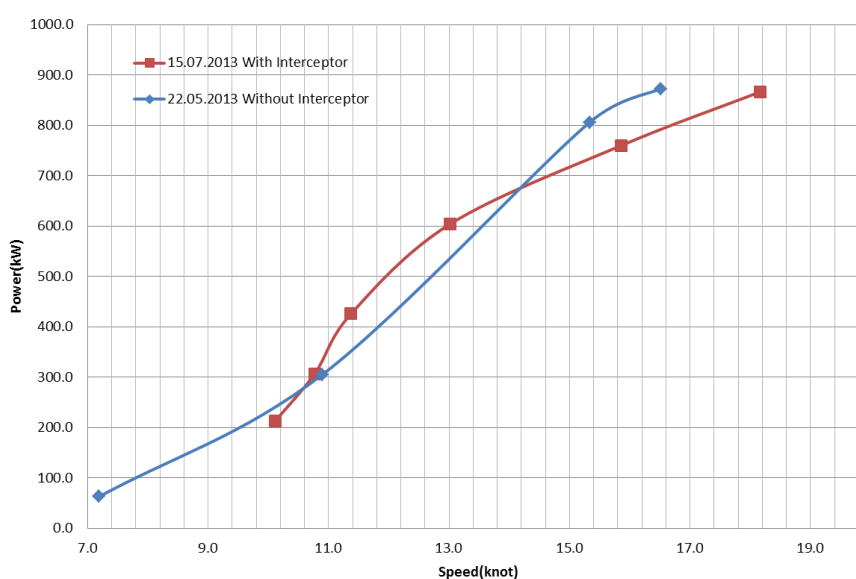


Fig. 13 – Effect of interceptor on the trial performance of The Princess Royal

The Princess Royal had a pair of fixed pitch propellers designed to meet varying loading conditions for her different missions. Her propeller's open water curve displays a maximum propeller efficiency of 63% at an advance coefficient of $J = 0.68$, while the efficiency becomes 57% at design advance coefficient $J = 0.56$. The propellers were designed for the lighter initial design condition whereas they now operate in more demanding actual (as built) condition with a 19% heavier displacement. Based on the full-scale observations the cavitation inception speed for the propellers is around seven knots and they display well-developed steady tip vortex and sheet cavitation (~20%) at her design speed (15 knots). The strength and extent of these cavitations increase with increasing speed and tip vortices reach at the rudders. Occasional hub vortex and tip-hull vortex type cavitation can be observed between the flat observation windows and the propeller tip for the latter. Prior to her launching the port side propeller was coated by silicon based Intersleek 900 antifouling to investigate its effect on propeller fouling. However the coating was almost completely removed due to the most likely cause of cavitation by April 2012.

During her first drydocking, apart from the fitting of the interceptors, the forward parts of the lower fenders lines, which were interfering with the free surface, were removed at both sides of the hulls. It was also noticed that the original rope cutters, which were like a circular sharp discs, were causing severe cavitation around the hub and deflected wake flow was destabilizing the steady sheet cavitation. Hence they were replaced by more conventional and less pronounced rope cutters in-line with the wake flow.

5. Some recent & future activities

Since entering into service in October 2011, The Princess Royal has been operating successfully contributing to various teaching and research activities as well as in industrial consultancy activity and engagements.

These activities so far have covered a large spectrum of services and some which are summarised as follows: (1) To demonstrate various sampling techniques to undergraduate marine scientists on the vessel; (2) To conduct commercial bird survey over Blyth Wind Farm site using the purpose built Observation Platform; (3) To conduct tidal survey along Firth of Forth deploying tidal data monitors; (4) To continue long term sampling program at Newcastle University's "Standard Plankton" site and also providing live/preserved samples for teaching; (5) To offer trips to School kids to increase their interest to sea, marine science and technology; (6) To provide service for tidal data monitors and wave rider buoys at the Blyth Wind Farm site; (7) To serve as platform for professional photographers and students putting together images of the sea and people at sea working; (8) To participate in the annual University "Open Days" to attract future marine scientist and technologists; (9) To be used as a marine engine lab for the marine technology students; (10) To be utilised as a continuous data gathering weather station for super yachts racing; (11) To serve in monitoring of various hull and superstructure coatings over time to assess their performance during their product development stage; (12) To provide a stable deployment base for small ROV's investigating the sea bed and also some work on the NOAH platform off Blyth belonging to NaREC; (13) To conduct sediment sampling for continuing the long term spring/autumn sampling program

off the North East coast; (14) To provide service to Cooperative Research Ships (CRS) group to investigate the shaft loads, hull pressures and vibrations as well as cavitation observations. The measurements were performed by Lloyd's Register. Strain gauges were applied just forward of the propeller to measure shear forces and bending moments on the shaft. Additionally accelerometers were located around the port hull aft structure, along with 4 pressure transducers above the propeller. The full scale data will subsequently be used to validate CRS software, in particular the loading of the propeller whilst manoeuvring at speed. Figure 14 shows the strain gauge set up when the vessel at drydock;

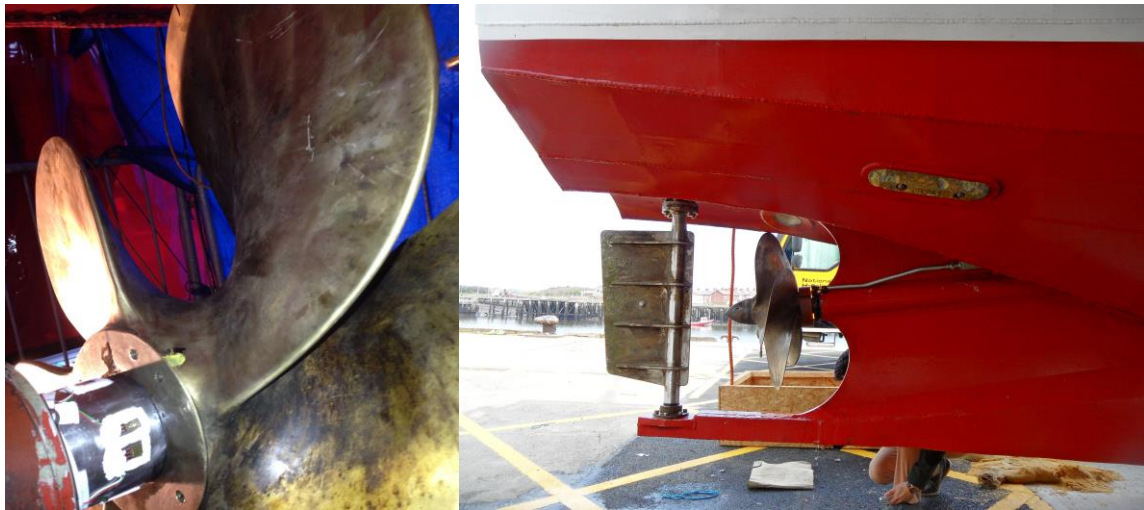


Fig 14 – Set-up for the strain gauge application on the port propeller shaft of The Princess Royal

(15) As part of a national project to conduct acoustic survey of wind farms using a towed hydrophone array and fixed to investigate their effects on mammals and hence provide baseline data set for use by the renewable industry; (16) To provide basis for the simulation of real life commercial survey work for MSc projects for marine science students; (17) To conduct annual trawling survey to ascertain the availability of sandeels available as a food source to the local bird population on Farne Islands to investigate feeding patterns and habits of the birds of international importance; (18) To conduct a large scale survey of dredging materials taken from the Tyne and dumped at sea to determine the benthic populations in the contaminated area and a control area; (19) To conduct survey for monitoring lobster population in a test area off Blyth - this has involved capturing the animals using pots, tagging them and studying re-capture rates. A secondary element of the project was to tag the animals with acoustic tags which could be picked up by an array of static hydrophones placed in a grid by the vessel. This was used to triangulate and fix the position of individual animals and track their movements over the sea bed for several weeks to determine whether these animals are transient or remain in the same basic area permanently; (20) To capture via pots of 8500 and release with tags for re-capture later in the year by commercial fishing vessels with the aim of monitoring the growth rates of various types crabs; (21) To capture live specimens for the aquaria at the Dove Marine Laboratory and Ridley Building of the University; (22) To carry out sediment sampling, underwater camera work and benthic population surveys prior to construction of NaREC's NOAH platform and eventually the

turbine themselves; 23) Prototype Tidal generator testing developed by current2current and tested by NaREC for initial testing of the theory in practice. As shown in Figure 15, using a specially designed and manufactured frame, the turbine deployed and towed at sea; the movement of the vessel through the water was used to replicate the tidal flow with the added benefit of being able to set any particular rate desired to suit at any time.



*Fig 15 – Set-up for deployment and towing of a prototype tidal turbine on board
The Princess Royal*

(24) To conduct a survey of white beaked dolphins off the North East coast so as to study these little known creatures in these waters with the aim of determining if these animals sighted here are the same or a separate population as the others elsewhere around the UK;

(25) To participate in Foghorn requiem event as part of a large scale public event to demonstrate the North East's maritime heritage;

In addition to the above activities the flexibility and multi-purpose nature of the Princess Royal has played an important role recently in securing two high profile and multi-European R&D projects SONIC (Suppression of Noise Induced by Cavitation) [15] and SEAFRONT [16]. The SONIC project has started in 2012 by a well-balanced consortium of 14 participants from seven EU countries and will be completed in 2015 under the 7th Framework Programme of the EC. The aim of this project, where Newcastle University's research vessel, The Princess Royal, will be used as a benchmark vessel to produce full-scale data, to help to develop tools to investigate and mitigate the effects of underwater noise generated by shipping, both in terms of the footprint of an individual ship (a "noise footprint") and of the spatial distribution of sound from a large number of ships contributing to the sound (a "noise map"). The details of this project are reported in a dedicated presentation in this conference in [17]. While this paper is prepared, the members of the SONIC consortium are preparing for the first set of trials with the Princess Royal within Work Package 2 of this project to be conducted in early September 2013. The main focus of the trials is to measure the underwater radiated noise generated by the Princess Royal using a service vessel where the hydrophones will be deployed at three different depths, namely 100m, 50m and 20m. While the underwater radiated noise is being measured off-board, further simultaneous measurements will be taken on-board The Princess Royal in relation to propeller cavitation by using high-speed video in combination with borescoping, as well as directly from the observation windows. These will

be further supported by the hull pressures and vibrations measurements using dedicated pressure gauges and accelerometers at the aft end. The on-board noise measurements in the engine room will be also taken to further analyse the hydrodynamic noise of the propellers. Figure 16 shows typical views from the engine room and wheel house: the picture on the left shows two pressure gauges and accelerometer fitted in the downstream of the propeller before the rudder; middle picture shows borescoping in action and picture on the right displays data acquisition equipment laid in the wheel house which had an open platform for the ease of communication.



Fig. 16 – Typical set-up for the pressure and acceleration gauges on the port demi-hull (on the left); borescoping in action (in the centre); a view of data acquisition system layout in wheel house of The Princess Royal

SEAFRONT (Synergetic Fouling Control Technologies) has been recently awarded an Integrated Project under FP7-OCEAN.2013.3 with 19 members and a budget of €11.5M. The main objective of the SEAFRONT project is to significantly advance the control of biofouling and reduce hydrodynamic drag by integrating multiple technology concepts such as surface structure, surface chemistry and bio-active/bio-based fouling control methodologies into one environmentally benign and drag-reducing solution for mobile and stationary maritime applications. In parallel, a combination of laboratory-based performance benchmarking and end-user field trials will be undertaken in order to develop an enhanced fundamental/mechanistic understanding of the coating-biofouling interaction, the impact of this on hydrodynamic drag and to inform technology development and down-selection of promising fouling control solutions. This project basically aims to facilitate a leap forward in reducing greenhouse gas emissions from marine transport and the conservation of the marine ecosystem by adopting a multidisciplinary and synergistic approach to fouling control.

Within the framework of SEAFRONT, The Princess Royal has two important roles to play in Work Package 5 where the benchmarking of the selected coatings and performance monitoring in situ will take place. In relation to the first role, the moon pool plug of The Princess Royal will be fitted with a specially designed and manufactured strut where number of standard sample plates coated with different antifouling will be attached, as shown in the following concept sketch at Figure 17. This will allow the sample plates to develop fouling on their coated surfaces in real life and under dynamic conditions. The growth and effect of fouling on the drag characteristics of the sample plates will be evaluated using other laboratory based testing devices (e.g. LDV and/or pressure drop flume) in this project to investigate the effect of slime on coatings in particular.

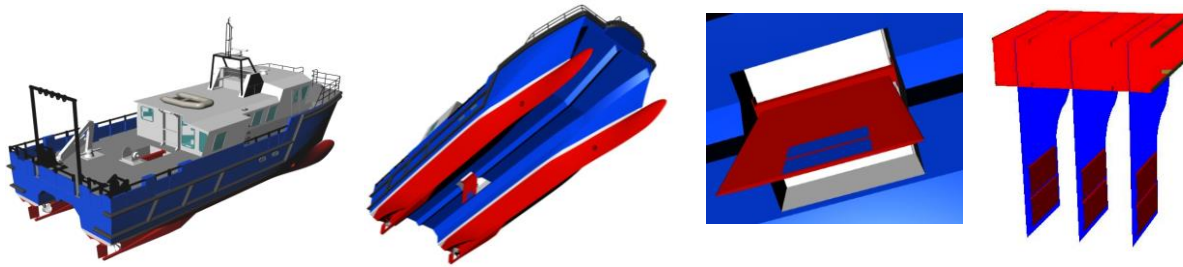


Fig. 17 – Concept fouling sample plate arrangements on the moon pool plug of the Princess Royal

In relation to the second role of The Princess Royal in the SEAFRONT project, the port shaft of the vessel will be equipped with a permanent data acquisition system as the starboard shaft where the thrust, torque, bending moment and shaft speed can be continuously monitored by a dedicated system, developed by the Design Unit of Newcastle University as shown in Figure 18.

Having equipped both shafts of the vessel, continuous performance monitoring of the vessel will be conducted for fouling growth with different coating applications and hence to assess the performance of new coating systems to be developed in the SEAFRONT project

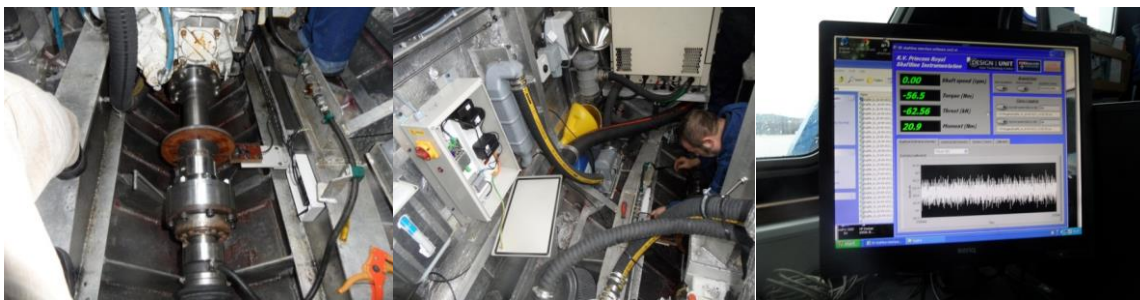


Fig. 18 – Some views of the present shaft loads and speed monitoring system on starboard shaft The Princess Royal

6. Conclusions

The Newcastle University's marine technology experts, keeping with the tradition of in-house design and locally built research vessels, designed and realised a novel multi-purpose research catamaran, "The Princess Royal". She has a flexible speed range to meet the increasing marine science & technology demands of the university as well as the industrial needs of the North East region of England.

Since her introduction to service in October 2011, the new research vessel has been operating successfully meeting her diverse mission objectives without any design flaw. This is allied with ever increasing consultancy activities and growing reputation in the region.

The unique catamaran Deep-V hull form combined with multi-purpose and flexible mission requirements makes The Princess Royal readily available and easy to access platform for

diverse marine science and technology research, teaching, engagement and industrial consultancy activities as illustrated in the paper.

Acknowledgements

The Authors acknowledge the kind collaboration from The Princess Royal skipper Neil Armstrong in documenting her recent activities and George HG Mitchell for editing the paper.

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